

Briggs (R)

ROBERT BRIGGS, C. E.
United States Engineer Office,
No. 1135 GIRARD STREET,
PHILADELPHIA, PA.

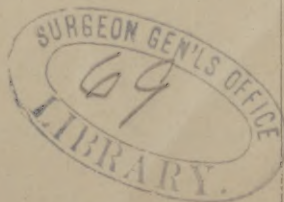
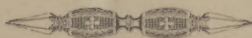
THE PROPERTIES OF AIR

RELATING TO

VENTILATION AND HEATING.

BY ROBERT BRIGGS, C. E.

REPRINTED FROM THE
JOURNAL OF THE FRANKLIN INSTITUTE,
For AUGUST and SEPTEMBER, 1881.



PHILADELPHIA:
MERRIHEW & LIPPERT, N. W. cor. Fifth and Chestnut Sts.
1881.

[Reprinted from the JOURNAL OF THE FRANKLIN INSTITUTE, August, 1881]

THE PROPERTIES OF AIR RELATING TO VENTILATION AND HEATING.

By ROBERT BRIGGS, C.E.

Reprinted from the *Sanitary Engineer*, with additions by the author.

The surface of the earth is covered by a gaseous body, some forty or fifty miles in depth, which is called the atmosphere. Chemistry has discovered and isolated various gases, some of which, so far as further separation is concerned, may be deemed elementary, while some are chemical compounds of definite proportions of other elementary gases and bodies. In some cases bodies which in their elementary form, at temperatures subsisting in nature, are solid, become portions of chemical combinations as gases at similar temperatures.

The atmosphere is composed mainly of a mixture of two elementary gases, together with small but appreciable quantities of two other gaseous bodies, products of combustion; beside other gaseous bodies of various kinds, in nearly inappreciable quantities, the latter varying somewhat in character in inhabited localities. Its substance, as a

whole, is a compound gas of nearly uniform composition known as the AIR.

The air, when uncontaminated by local causes, has been found by the most painstaking and careful observations, in all parts of the earth, and at all heights, from the level of the sea to the top of the highest mountains reached by man, or the greatest elevation attained by the balloon, to have identically the same components. Omitting the two smaller constituents, in 100 volumes of air there are 79.1 of nitrogen and 20.9 of oxygen, or in 100 parts by weight there are 76.9 of nitrogen and 23.1 of oxygen; oxygen being heavier than nitrogen in the proportion of 16 to 14. These proportions differ a little from a chemical compound of four parts (weights) of nitrogen to one part of oxygen, and beside this difference it must be stated there is certainly no chemical combination of the gases in air—they are simply intermixed. All gases or gaseous bodies mix with each other indefinitely and perfectly, whatever may be their relative densities or weight, a difference in the most extreme case of over 250 to 1, and they never separate from each other, wholly or partially, except by condensation of some of them from a gaseous form (or vapor) to that of a liquid by reduction of temperature or increase of pressure or both.

Beside nitrogen and oxygen in the air, there is always present carbonic acid and vapor of water. Of the carbonic acid the quantity is quite variable, but very small in all cases. Pure country air has an average of from $3\frac{1}{2}$ to 5 parts by volume in 10,000—4 parts being considered by most physicists as a proper quantity to adopt as appertaining to *pure* air. Four per cent. of one per cent. may convey the idea to readers. While the quantity of vapor of water present is yet more variable, as it depends on the temperature of the air at the time as well as upon the locality, not only where the air may be taken, at any place of observation, but where the air came from, by the winds, to reach that place. The quantity of vapor of water present in air is called its humidity, and air is said to be saturated with humidity when it holds as much vapor as it can without its condensing into water as a liquid.

We commonly know vapor of water as *steam*. At 212° and under the ordinary pressure of the atmosphere (which we will speak more about hereafter) water boils, and if the temperature is maintained, it will all boil away in the air. But vapor of water exists in contact with water without boiling, at all temperatures, and if the pressure of

the atmosphere which rests upon it is taken away, water will boil at any temperature whatever, dependent on the extent of relief of pressure. It is a curious truth that water only exists as a liquid because it is held down by the pressure of the atmosphere upon its surface.

The natural temperatures of the climate we live in, omitting extremes, are, say, from 10° to 85° Fahrenheit. The quantity of vapor of water in each cubic foot of saturated air (at 30 inches of barometric pressure) has been ascertained with great care by eminent French physicists. This quantity is very small in any case, being only 4 per cent. by volume at 85° , and it falls off rapidly as the temperature falls; at 65° , or 20° fall of temperature, only half as much, or 2 per cent., can exist; at 45° , another fall of 20° , but 1 per cent. is found; at 28° , but $\frac{1}{2}$ per cent., while at 10° only $\frac{1}{4}$ of a per cent. of the volume of air can be invisible aqueous vapor. So much as even these small quantities do not exist in air generally, as the air which has derived its moisture from water or damp surfaces will, from the action of currents and winds, ascend to the upper, colder atmosphere, where it will deposit the same moisture by condensation, into clouds, with rain, hail or snow, when great quantities of moisture are condensed, and much loss of heat accompanies the position of the cloud as regards its elevation from the surface of the earth. The course of the winds will bring this dried air again near the surface at another place; so that the humidity of air in our country may at any time be only 30 or 40 per cent., or even less, of what would constitute saturation for air of the same temperature. The average humidity of the Eastern States is from 60 to 70 per cent. of complete saturation. The degree of saturation is measured by the *dew-point*, which is the temperature that is indicated by a thermometer, artificially cooled until a deposit of dew or condensed water appears on the bulb.

Air, as it is found in the neighborhood of our cities, and in the seasons of growth in the country, generally has very small quantities of other gases in its composition. The most general are ammonia, sulphuretted hydrogen and sulphurous acid gas, with numerous others of local derivation, especially near factories; but the quantities of such impurities present in the open air are even smaller than those given for carbonic acid or vapor of water, so that fresh air everywhere can be held, as before stated, to be mainly nitrogen and oxygen. Only the most delicate tests, where the hundredth of a per cent. is a unit, serve to measure the quantities of gaseous bodies vitiating air.

Beside the gaseous impurities referred to, there exists always in air of inhabited regions very small quantities of floating organic matter, composed of fragments of organic origin, vapors of the same source, like odors, for instance, microscopic germs or living organisms, together with dust of minerals or metals, smoke, etc., forming an insignificant part of the atmosphere, nearly inappreciable in amount by weight or measure, but of the greatest importance in effect upon the air of ventilation, as will be made to appear further on in this paper.

The main chemical characteristics of the gases in air are as follows: Oxygen is the most abundant element in nature. It forms, as stated, one-fifth of the atmosphere; it also is eight-ninths of the substance of water, and about one half of all solid bodies of the earth—at least, of the crust of it so deep as we can investigate its formation. In its free state, and its existence in the air mixed with nitrogen can be considered free, it combines chemically with nearly all other elementary bodies. This combination is attended by evolution of heat, and is known as combustion.

Nitrogen, which is the chief constituent of the air, has few inorganic chemical combinations with other elements. It is an essential and considerable part of all animal tissues which are composed mainly of carbon, hydrogen, oxygen and nitrogen, and also an essential but very small part of vegetable tissues which consist principally of the first three bodies in the list.

Carbonic acid is the product of combustion of carbon, where two and two-thirds parts of oxygen by weight enter into combination with one part of carbon, also by weight, and form a colorless gas, about one and a half times heavier than air in equal volumes. It results from the burning of fuel—carbonaceous materials, either recent vegetable growths or the fossils of former vegetable growths—and from the slow oxidation of organic tissues called decay, beside being the chief product of respiration. Volcanic action, as well as some processes of combustion which take place in various localities under the surface of the earth, evolves large quantities of carbonic acid. On the other hand, while these sources of carbonic acid are in constant action, nature is restoring the equilibrium of condition; as all vegetable growths are absorbing carbonic acid, assimilating into wood tissues the carbon, and setting free the oxygen. It cannot be said, however, that the condition of the air is dependent upon vegetable growth to keep

down the proportion of carbonic acid, as it has been estimated that if the vegetable growth of the earth were to cease for two thousand years the effect of respiration and combustion in vitiating the air could only be detected by the nicest chemical analysis.

Carbonic acid is an innocuous gas, quite harmless to animal life except when it is substituted for oxygen in the air for breathing, and except in so far as its presence in large proportions interferes with the natural secretion from the lungs and possibly from the skin.

Vapor of water is the product of the combustion of hydrogen where eight parts of oxygen by weight combine with one part of hydrogen (the volume of the one part of hydrogen being twice that of the eight parts of oxygen). It is a colorless vapor or steam, about five-eighths as heavy as air, in equal volumes. When condensed as liquid water it is the chief constituent of organized bodies, forming the greater part of their weight. Water also plays an important part in the mineral kingdom as the water of crystallization of many minerals. Many substances dissolve in water. All animate creatures who live upon the surface of the earth require water as a liquid to drink, but the presence of vapor of water in the air does not seem to be absolutely essential to the existence of animals—except, perhaps, it may afford a mitigation of the extreme heat of the sun's rays as they shine through our atmosphere. But, on the other hand, all vegetable life demands, as a primary necessity, considerable vapor in the air, and in a warm saturated atmosphere it grows and thrives with the greatest luxuriance. Like carbonic acid, aqueous vapor is harmless to animal life, except when present in so large quantities as to interfere with natural secretions; but, as it condenses from air, at any usual temperatures in the habitable part of the globe, until the quantity of water present cannot exceed four to six per cent., the danger of such interference is almost entirely removed.

Having discussed the constituting elements of *air* and their characteristics as chemical bodies, some of the physical properties which bear important relations to ventilation and heating may next be noticed. The three conditions of material substances are gaseous, liquid and solid. An ideal perfect gas is perfectly fluid and perfectly expansible or compressible; relief of pressure or the addition of heat, with permission to expand under the same pressure will cause an indefinite enlargement of volume proportionate to the pressure or heat, while increase of pressure or abstraction of heat under constant pres-

sure produces proportionate reductions of volume also indefinite in amount. Although the discoveries of the past three years have rendered it nearly certain that no gaseous body whatever exists which at some pressure or temperature does not lose its gaseous form and become liquid, yet within the range of temperature and pressure of nature on the surface of the earth, the air may be treated as conforming to the ideal laws of a perfect gas.

It is not the less a material substance that *air* is a gaseous body. Its weight for a given volume, under a given pressure and at a given temperature, is well known. Thus at the pressure of 14.7 pounds upon a square inch and at a temperature of 32°F., one cubic foot weighs 0.0807 pound; or 12.4 cubic feet weigh one pound. Now, this pressure of 14.7 pounds on a square inch is the atmospheric pressure found to exist on the surface of the earth, and is the equivalent to 2116.3 pounds on a square foot. If 12.4 cubic feet weigh one pound, it would take a column of air of 26,227 feet to exert the load of 2116.3 pounds on the square foot, or very nearly five miles high. But the air changes in density as the pressure is reduced; or, in other words, as weight of the column of air becomes less and less towards the top, the volume of each cubic foot increases, so that the atmosphere is really 40 to 45 miles in height in place of the 5 miles which would exist if it had a uniform density.

The pressure of air is measured by the barometer, and 14.7 pounds to the square inch corresponds to 29.92 inches of a column of mercury in the mercurial barometer. This instrument may be briefly described as a glass tube about three feet in length, with one end closed, which tube having been filled with mercury when the closed end was downwards, is reversed into a shallow cup also holding mercury; when the column in the tube will leave the upper or closed end (and form a vacuous space) and descend into the cup, so far as the pressure of the air on the surface of the mercury in the cup will not support the column. There is found to exist at any place not much elevated above the level of the sea from 28 to 31 inches of length of this column; or, in other words, of difference in height of surface of the mercury near the top of the tube and that of the open cup at its foot. These three inches of variation of barometrical height are the limits of usual variation of atmospheric pressure.

The volume of air under any given pressure is much affected by heat. In common with most gases (and probably of all where the

temperature of the gas is considerably above the point of liquefaction), air expands or contracts $\frac{1}{491}$ part of its volume for each degree (Fahrenheit) of temperature above or below the freezing point. This change of volume is the great natural agent in promoting that circulation of the air and distribution of the heat from the sun which makes our globe habitable. A correct appreciation of its effect upon the air may be had by examination of the following table, which includes only a few usual atmospheric temperatures. The same laws, with small modifications, govern the volumes and densities of air to the highest temperature of combustion :

Temperature of dry air, degrees } Fahrenheit..... }	0°	10°	20°	32°	40°	50°	60°	70°	80°	100°
Volume of same weight, of air } under the same pressure..... }	459	469	479	491	499	509	519	529	539	549
	0.935	0.955	0.976	1	1.016	1.07	1.057	1.077	1.098	1.138
Density for constant volume.....	1.070	1.047	1.025	1	0.984	0.965	0.946	0.928	0.911	0.878
Weight per cubic foot-pounds.....	0.0863	0.0847	0.0828	0.0807	0.0794	0.0779	0.0765	0.0749	0.0735	0.0709

If, however, the pressure upon any given volume of air becomes greater or less, its temperature will then be found to have increased for the greater pressure and to have diminished for the less pressure. It results from this that the air upon the top of mountains, where the barometric pressure is greatly reduced, is found to be much colder than at their feet, until at the elevation of from four to five miles above the elevation of the sea a region of perpetual frost, even in the torrid zone, is reached.

There are two recognized standards of measurement of heat of substances. The first is that of the intensity or temperature. All bodies of unequal temperatures possess a tendency to equalize their temperatures by transfer of heat between themselves, when such bodies are either in actual contact (in which case the process is called conduction or convection), and also when they are in some degree in proximity to each other (in which latter case the process is denominated radiation), some, if not all, of the heat rays being found to pass through most gases and through some solid bodies. Such gases or bodies are denominated diathermanous. As substances generally expand by the increase of their heat and contract with its decrease, the extent of this

change of dimension between certain temperatures determined by natural phenomena has been used as a measure. The phenomena referred to are the freezing and boiling of water, and the temperatures communicated to thermometers (heat measures) by water at the freezing or boiling point (under defined atmospheric conditions) established limits for a range of expansion, which range is divided into parts called degrees. Three scales of division have had practical use, but one of them (Reaumur's) of 80 parts may be considered as superseded at this time. The other two are: first Fahrenheit's, where 180° of equal expansion are made between freezing and boiling, and where the freezing point is called 32° , and the same rate of equal expansion (contraction in this case) is carried downward below the freezing point to an imaginary zero; bringing the boiling point $32^{\circ} + 180^{\circ} = 212^{\circ}$ above zero; and the second, Centigrade, where the freezing point is called zero, and 100° are spaced off from zero to the boiling point. By the English speaking nations the Fahrenheit scale is used as a popular scale almost altogether, and to a great extent as the scientific one. In other countries the Centigrade scale is in general as well as scientific use, and the next fifty years will probably witness its universal adoption in all countries. The mercurial thermometer is too well known to need description. The principle of measurement of temperature by the expansion of a body by heat is extended above the boiling point by degrees of supposable equal values to $10,000^{\circ}$, $15,000^{\circ}$, $18,000^{\circ}$, the last being the theoretic heat of carbon burning in oxygen, and is carried below the freezing point in the same way to the lowest temperature of existence in nature, and *to the utmost cold supposed to be possible*. The contraction of gases by removal of heat of one degree Fahrenheit, was stated to be $\frac{1}{491}$ part of the volume at 32° . Now, if it be imagined that the contraction were carried on for 491° , the gas must obviously disappear at the next diminution. This imaginary temperature of $32^{\circ} - 491^{\circ} = -459^{\circ}\text{F}$., has been deemed the zero of absolute temperature, and it has been found that by adopting this supposed value in computations, the laws of expansion and elasticity of air, or gases, together with those of accompanying heat, can be expressed satisfactorily.

The second standard of measurement of conditions of heat refers to the quantity of heat which may be taken up or given out in effecting changes of temperature in the various substances. For this purpose water is again selected as the means for establishing a thermal or heat

unit. The English heat unit is taken as the heat appertaining to one pound of water heated one degree Fahrenheit. The foreign and scientific heat unit is the heat belonging to one kilogram of water heated one degree Centigrade, and is 3.97 times that of an English heat unit; but the English heat unit continues to be used in most treatises on applications of heat in the English language, and will be the only one referred to in this paper.

The specific heat of a substance is that quantity of heat, expressed in heat units, which must be transferred to or from a pound of that substance to effect a change of temperature of one degree. The quantity varies greatly for different bodies, and varies also in some measure at the different points in the scale of temperature in most of them. In the latter regard, however, the variation is so small that we can accept certain values which have been ascertained by experiment, and will be found in tables of specific heats of substances in books on physics as sufficiently accurate for practical purposes. For gaseous bodies the uniformity of specific heat at different points in the scale of temperature is more closely preserved than for solids or liquids, but these bodies are found to have *two values* for specific heats: one for the increase of temperature of one pound of gas, one degree, where the gas is permitted to expand under constant pressure; and the other, where the gas is enclosed so that, in place of expanding, the pressure increases in accordance with a certain law of elastic force dependent upon the addition of heat. Thus the specific heat of air, under constant pressure, is 0.238 heat unit; that is, 0.238 pound of water, losing one degree of heat, will impart to one pound of air (about $13\frac{1}{2}$ cubic feet at 70°) one degree of heat, while the volume of the air will have increased, under constant pressure, $\frac{1}{525}$ th part. On the other hand, the specific heat of air, with constant volume, is 0.169 heat unit only; one pound of the air retained (to $13\frac{1}{2}$ cubic feet in the supposed case of 70°) in its original volume will be heated one degree by 0.169 pound of water losing one degree. This value of specific heat for constant volume does not apply to all gases, although nitrogen, oxygen, hydrogen nearly conform to the figures given.

The specific heat usually quoted and applicable to the theory of heating and ventilation is that of constant pressure, or 0.238 heat unit for air.

To complete this statement of the effects of heat, latent heat must be mentioned. Whenever any material substance passes from one of

its three conditions — gaseous, liquid or solid — to another, heat units are absorbed or given out, often in enormous quantity, without any apparent change of temperature of the transformed substances. Thus water at 212° requires the addition of 966 heat units to transform it into steam of 212° . Evolution or absorption of latent heat also accompanies chemical combinations.

One more property of heat should be named. Heat is a measure of force expended or utilized, and one heat unit represents the force of lifting 772 pounds to the height of one foot \equiv 772 foot pounds.

Resuming the consideration of the physical properties of air.

The beginning of this paper mentions that *very* small quantities of various substances which cannot be considered as gaseous bodies were to be found in the air of habited or habitable places. Generally, especially in towns or cities of the temperate regions where manufacturing callings or the comfort of the inhabitants demand the use of fires, the main portion of these impurities of air consist of dust of minerals, and metals — smoke (which is principally dust of charcoal or mineral coal), and similar bodies reduced to so fine a state of powder that the adhesion of air to the particles prevents their settling in it, except so slowly that they may be said to float, and as floating bodies will have been dispersed with the currents; and they may be in some measure diffused by the inter-currents of diffusion of vapor of water or carbonic acid or other gaseous bodies with which they were particularly associated in their origin. The effect of this adhesion of air to particles of matter can be appreciated by stating that, but for it, rain drops would reach the ground with an acquired velocity equal to that of shot from a gun; and by it the impact of hail-stones, even of the largest size, is modified so far as to reduce the injury they occasion, to the destruction of glass, defoliation of trees, and similar results, such as might happen from stones thrown by the hand. In the case of a hail storm the phenomenon is produced by a violent ascending current of air, which at the height of five to eight miles reaches the region of perpetual frost, where the hailstones are formed, and the stones descend through and against a current of from 20 to possibly 200 miles per hour.

The dust referred to, after all, except in localities where decidedly injurious fumes are generated, or in workshops, or any business where a volume of dust or smoke is created, or the exposure of the workman to breathing it, is improperly guarded against, can only be considered

rather as objectionable than noxious. This question of means of prevention or removal of dust or smoke will come up again when considering the practical applications of ventilation.

Odors or smells constitute palpable impurities—vitiations or, perhaps, quite harmless portions of the air. Some of them are unquestionably dusts of solid bodies; others are definite chemical gaseous bodies; others, again, are seemingly in combination with the vapor of water, in which they are dissolved in the atmosphere. Dust of organic matter; small particles of the skin, and fluty matters detached from the skin are abundant in the air of all houses; in the air of the streets similar exhalations from horses and other animals can be detected; in the air of the country, vegetable particles predominate. These dusts are in every stage of decomposition. When first separated from their source they are generally undecomposed and inodorous, but sometimes, like pollen, they possess the power of affecting the sense of smell; in moist atmospheres they rapidly decompose, having become the soil for numerous microscopic growths which accompany, and it is now satisfactorily determined, occasion the decompositions.

It must be borne in mind that the *quantity* of organic matter described so briefly in the preceding paragraph is exceedingly diminutive as compared with the volume of air. Light as air is, not the one hundred millionth part of its volume for pure air on high ground, or about one five millionth part in a crowded railway carriage (as deduced from figures of Dr. Angus Smith), is organic impurities. Yet to a very small portion of this very small portion of the air is now attributed, by the best authorities, the greatest danger from breathing of vitiated air.

It has been long known that fermentation or some similar action accompanies most, if not all, organic decompositions; and it was reserved to Drs. Schreëler and Pasteur, especially to the researches of the latter to demonstrate that countless germs of vegetables and infusoria exist in the air, which will develop wherever suitable organic matter is found to support their growth. These views were combated by several writers, some of whom, admitting the fermentative growths, supposed or advocated their origin by spontaneous generation. But this last view has now been satisfactorily refuted by many experimenters; Prof. Tyndall's investigations being very conclusive in showing that with pure air no change of the most decomposable substances and solutions commences. Prof. Tyndall's test for the purity of air is to

allow a sunbeam to shine down a tube containing air which has been filtered through cotton-wool. The smallest particles of dust, germs or grains beyond the power of discernment by the microscope, are illuminated by this test to brilliant points, until their presence becomes evident to the observer.

It is positively known that different chemical changes are brought about by different germs. Alcoholic or acetous (vinegar) fermentation, lactic acid, butyric acid, etc., proceed from different vegetable or organic growths. It finally seems probable that the whole train of epidemic diseases owe their origin to atmospheric germs which find their suitable organic matter for growth in the human system.

The organisms themselves are minute almost beyond the limits of conception. One of the most common, the Bacterian termo, which is a living organism, "has a wasp-formed body, each enlarged part being about $\frac{1}{11000}$ of an inch long and $\frac{1}{43000}$ of an inch wide, joined by a filament of extreme thinness, about $\frac{1}{14000}$ of an inch long; and has a 'flagella' $\frac{1}{7000}$ of an inch long at each end, not over $\frac{1}{1000000}$ in width, and so thin as to be undiscernible in the side view. The flagella is lashed incessantly." What must be the magnitude of the germs of this perfect organism? Beside the germs of the Bacteria, those of Vibrios, Mycodermes, Mucidines and Torule are given by Pasteur and others, as of known organisms whose characteristics and purposes are well established. The almost immediate occurrence of fermentation of some particular kind in each fermentable liquor when exposed to common air in any place, and the complete suspension for an indefinite time of fermentation when only *pure* air, tested as Tyndall has described, comes in contact with such liquor, must be accepted as proof of the agency and universality of atmospheric germs. Heat far beyond the boiling point will not kill certain of these germs, and some defy certain chemical agents which are destructive of life generally.

Each new consideration of the subject of the effect of air on the health of mankind, adds more evidence or reasoning to support the view that gaseous impurities are fraught with but a very small portion of the danger which appertains to the organic vitiations.

* It should be here remarked that the basis of the *germ theory* is, that all natural decompositions of organic substances (in contradistinction from decompositions, by fire or chemical action) are growths. Growths in themselves healthful of their kind (same as the lion or the mosquito

have healthful lives—the oak or the weed have healthful growths). Each growth, it may be descending in the scale of growth and ascending in another path, to be again reduced. A cycle of vitality from the lowest organism through the vegetable and animal life to man, and returning by a retrograde course (if it be retrograde) to a new train of existence.”—[Excerpt from a report on the sanitary condition of a building, by the writer.]

The next step in the course of the investigation is to consider the quantities of air requisite for the health and comfort of the human occupant of the ventilated room or place, for a given interval of time. These quantities are composed of several distinct requirements, the most essential of which are the *necessities* of respiration and of absorption of the vapors of transpiration; inadequate supply of air for these purposes resulting in suffocation. Another requirement for dwellings, is the supply of air for fuel or for lighting, in the latter case for the dispersal of heat in some degree. But all these requirements, essential as they are, call for quantities of fresh air, quite insignificant in amount to the demands for dilution of the products of respiration, transpiration and combustion, so that the air of a dwelling shall have that degree of purity which is conducive to healthful residence.

The healthy adult man, in still life, in an atmosphere of normal condition (which, in our climate, may be taken at the temperature of 60° to 70° , with 80 to 70 per cent. of humidity), whether awake or asleep, inspires on an average, 30 cubic inches and expires a corresponding quantity, slightly dilated by heat and by chemical change at each respiration, and he breathes 16 times each minute; giving 480 cubic inches (or 0.278 cubic feet) of air demanded each minute. Let it be supposed that the air inhaled in pure air with 0.0004 its volume of carbonic acid gas, and to have the temperature of 70° with 70 per cent. of humidity; in such case, the exhaled breath will have a temperature of 90° ; and the entire volume will have been increased about $7\frac{1}{10}\frac{3}{10}$ per cent.; it will be saturated with moisture, which will form over $4\frac{1}{10}\frac{7}{10}$ per cent. of its volume; while the increase of weight, by taking up moisture and carbon from the lungs, will have been only $3\frac{6}{10}$ per cent.; at the same time, from the 20° rise of temperature, the density, as a whole, will have been reduced $3\frac{2}{10}$ per cent.; the carbonic acid gas in exhaled air will be $3\frac{8}{10}$ per cent. of its volume; and the quantity of oxygen of the inhaled air will have been reduced about $19\frac{3}{4}$ per cent.

The average respirations of an adult for one minute will tabulate as follows:

Table of constituents and products of 16 respirations, of 30 cubic inches each.

Constituent gases.	Inhalations at 70° temperature and 70 per cent. humidity. Wt. = 0.07443 lbs. per cubic foot.			Exhalations at 90° temperature, saturated with aqueous vapor. Wt. = 0.07204 lbs. per cubic foot.			Ratio of exhalations to inhalations.	Changes effected by the act of respiration.
	Wts. lbs.	Vols. c. ft.	Vols. cu. ft.	Wts. lbs.	Vols. cu. ft.	Vols. cu. ft.		
Nitrogen.....	0.015898	0.2181	0.7854	0.015898	0.2264	0.7615	1.0000 1.021	0
Oxygen.....	0.004542	0.0548	0.1973	0.003645	0.0456	0.1564	0.8000 0.821	-0.000897
Aqueous vapor.....	0.000221	0.0017	0.0003	0.003629	0.0140	0.0471	2.0000 2.587	+0.000408
Carbonic acid.....	0.000013	0.00011	0.0004	0.001246*	0.0113	0.0380	100.00 102.75	+0.001233
Total.....	0.020674	0.27771	1.0000	0.021418	0.2875	1.0000	1.0703	+0.000744

The difference of the changes in weight of carbonic acid and oxygen in the last column of the table = $0.001233 - 0.000897 = 0.000336$ lb., represents the weight of carbon taken from the lungs, being an actual combustion of so much carbon in the system (as appears from the breath) each minute.

To the casual reader it would appear that the computations of the above table were needlessly extended, especially when it is considered that the data are assumed averages, and not absolutely accurate; but the fact is, that the vitiations of air bear so small a part in relation to its volume, that it requires long lines of decimals to express them at all; and accuracy in the last figures is demanded, to make the proportions of what are admitted vitiations, or rather are admitted as the accompaniment or vehicle of vitiations, appreciable.

Beside the air needed for respiration, an uncertain quantity is both

* The quantity of carbonic acid exhaled, adopted in this table, is deduced from the experiments of Dr. Edward Smith, Proc. Roy. Soc., 1859.

† This column of vols. cu. ft. was obtained thus:

	Weights. Lbs.	Weight per cu. ft. at 70°. Lbs.	Cu. ft. at 70°.	Cu. ft. at 90° 549.520 lbs. 1.008.
N ₂	0.015898	0.0726	0.2181	0.2264
O ₂	0.004545	0.0824	0.0439	0.0456
H ₂ O.	0.000629	0.0466	0.0135	0.0140
CO ₂	0.001246	0.1142	0.0109	0.0113
	0.021418		0.2864	0.2973

needed and vitiated by transpiration. A constant exhalation of carbonic acid gas transpires from the skin; by no means so large in quantity as is emitted with the breath, but probably one-fourth or one-fifth as great. The regularity of transpiration nearly equals that of respiration. Accompanying this, it is probable that an absorption of oxygen, corresponding to the equivalent of oxygen in the carbonic acid, takes place. The best authorities do not seem to have found the expired air from the lungs to have lost more oxygen than the carbonic acid exhaled required; and as all authorities assert the exhalation of carbonic acid from the skin, it follows of course that the supply of oxygen to form this carbonic acid must be absorbed by it. The phenomenon of interchange of gases occurs with the cutaneous secretions, similarly, if not equal in extent, to what happens in the so-called revivification of the blood.

The exhalation of moisture from the skin, however, is a very variable quantity as compared to what exhales from the lungs. The internal temperature of the human being is perhaps 98°, while the comfortable and healthful temperature of the air in contact with the skin is from 10° to 30° below this point; the degrees of heat of the air, varying greatly with its hygrometric condition—or, in other words, with the proportion of moisture present. The loss of heat from the evaporation of moisture from the skin into the air, being far greater than the cooling effect of the air itself. In temperate regions, also, a large part of the person is protected by clothing, whereby the temperature of the air next the skin, under the clothing, is elevated, until, for instance in our climate, an admitted summer temperature of 70°, accompanied by 70 per cent. of humidity, is the standard of condition for the active man, although a higher rate of humidity (80 per cent.) is perhaps more conducive to luxurious comfort and ease.

Be this temperature and corresponding moisture condition what it may, the fact remains that by insensible perspiration, as it is called, a large amount of moisture is exhaled from every human being each day, hour or minute, and this moisture is laden with organic matter; and a certain quantity of fresh air is needed to absorb and dilute it, and the accompanying organic vitiations.

Some observers, after considering the relative quantities of liquids and solids taken as food and excreted daily, have estimated that from 1.5 to 2.5 pounds of liquid, must, on an average, be dissipated from the system of an adult in active life in the time named. The mean of

these quantities may be accepted as the loss by evaporation from the lungs and skin in occupied places = 2 pounds; when about 0.0014 pound will pass from the skin and 0.0004 pound is evaporated from the lungs each minute. On the other hand, the exhalation of carbonic acid, as before stated, is not nearly as much, probably, from the skin as from the lungs.

It should also be stated that a small quantity of nitrogen has been found to be absorbed by the lungs, and a very little ammonia is either given off, or is formed almost instantly, by decomposition of some of the emitted organic matter. These vitiations are, however, only appreciable by delicate observations, which observations have given such discordant results as to throw doubt on the experiments as bases of theory. Still it may be asserted that nitrogen is the natural and fundamental part of the atmosphere for the types of animal life on the face of the earth, and that no other gaseous body can be admitted to replace it; while oxygen, in the proportion in which it is always found in the air, is the necessary and sole active agent in sustaining life.

From all that has been said in this article, it will be evident that, for the purpose of breathing solely, only a little more than one-quarter of a cubic foot of air is needed each minute by the average healthy adult. Perhaps this quantity will be raised to one-third of a cubic foot when the air of transpiration is included. And that there must flow away from the person, by respiration and transpiration combined, also each minute, 0.0014 pound or 0.03 cubic foot of vapor of water at 70°. If these quantities of exhalations, small as they are, are positively and absolutely removed, and fresh air substituted for the first of them, a perfect ventilation will have ensued.

The sole mode of removal possible, is by diffusion and dilution. The purity of air in any occupied place can only be relative. A certain quantity of exhalations in a given time will mingle with a certain quantity of fresh air supplied in that time (neglecting the loss by transustion through walls, as septa, of some small quantities of carbonic acid and vapor of water, the latter especially when the exterior dew-point is low); and a definite ratio of the constituent parts of the air of any occupied place, will eventually be established.

It is customary to attempt the establishment of the proper quantity of fresh air by the ratio or percentage of carbonic acid *admissible* in a habited room. If it is supposed that twice the quantity of carbonic

acid is admissible in a continuously occupied room over that existing out-of-doors in fresh air, then 99.1 times as much fresh air as is needed for respiration, etc., must be supplied to dilute the exhaled air, a proportion which gives 33 cubic feet of air to each person per minute, with a result of 0.0008 volume of carbonic acid present.* The quantity of carbonic acid in any closed room will be further reduced by some diffusion at cracks of doors or windows.

Another method for determining the quantity of air needed is based on the diffusion of vapor of water. The supposition that the hygrometric condition of the air is to be elevated, say 5 per cent., will, if the temperature of the air of the room is 70°, allow the diffusion of 0.000056 pound of vapor per cubic foot of air, or for the 0.0014 pound of vapor emitted from the person each minute, 25 cubic feet of air to each person per minute.

Either of the above ways for *computing* the requirements of ventilation are purely empirical and founded on no reasonable or natural demand. The quantities they give, however, are about those adopted by the best authorities as the least for healthy persons, while double these quantities are required in hospitals. The air of dwellings and of hospitals has *proved* to be pure to the sense of smell with the quantities above stated, if the distribution and removal has been well arranged; with less quantities this is not the case. After all, the standard of purity of air is founded on the *perception* of an almost infinitesimal quantity of organic matter, and upon results of tests of health of dwellings, etc., and not upon the reasoning of the chemist.

Following the requirements of defined quantities of air for personal ventilation of the inhabitants of rooms, further demands for the purposes of supply of air to fuel used at times in heating them, and for the consumption of gas, oil or other material producing light by burning, should be investigated. What is needed for warming, however, may be more properly considered when discussing the heating of dwellings or other places, only remarking here that the quantity relative to what is requisite for *dilution* of the air of breathing, or for

* These figures are obtained as follows: Accepting the air for respiration at 0.2777 cubic foot at 70° per minute, and adding one-fifth for one for transpiration, we have 0.3331 cubic foot per minute. With the volume of air which shall give the requisite excess of 0.0004 CO₂ added to the normal air, the effect of raise of temperature may be neglected, when the ratio of volume of CO₂ in the exhalations to that in the inhalations becomes 1 to 99.1, in place of 1 to 102.7, which was the ratio for an increase of temperature of 20° (70° to 90°) $\frac{1.920}{1.11} = 90.1 \times 0.333 = 33.0 + 0.333 = 33.33$ cu. ft.

reduction of heat, is so small (while the diluted or vitiated air has sufficient oxygen not to be impaired for supporting combustion of fuel), that it drops out of consideration in the question of volumes of air to be furnished. And there is left for consideration at this time only what supplies of air are requisite for gas burners and oil or other lights.

The gas burner in common use will burn from three to six cubic feet of ordinary coal gas per hour; each cubic foot of such gas consumed will take up the oxygen of 6.1 cubic feet of air, and will require the presence of about 12.2 cubic feet of air at the point of ignition, in order to effect complete combustion. This double supply of air is found in practice necessary for the combustion of fuel of all kinds, under usual conditions, in air of usual temperatures, and the escaping gases, when burning hydrogen or carbon, will consist of vapor of water and carbonic acid (if the carbon is entirely burned), as novel chemical products, together with free nitrogen, and as much free oxygen as was not taken up in the chemical combinations. In the same way it was noticed that the air expired in breathing had been deprived of only about one-fifth of its original oxygen, and it was then accepted that such expired air was unsuitable for a new respiration.

The average gas burner in general use may be assumed to burn $4\frac{1}{2}$ cubic feet of gas per hour, and the quantities reduced to the unit of a minute, so as to be comparable with the estimate for respiration as previously established, give 0.075 cubic foot of gas, which takes up, by chemical combination, the oxygen of 0.46 cubic foot of air, and needs 0.02 cubic foot of air to accomplish the burning. The products of combustion, together with and including the free nitrogen and oxygen, forming the *gases of combustion*, have the volume of 0.97 cubic foot, when reduced to the temperature of 70° , at which temperature all the foregoing figures have been taken.

Thus it is seen that the demand of air for a gas burner (burning $4\frac{1}{2}$ cubic feet per hour) is very nearly three times as great as that for the respiration and transpiration of an adult man in still life. If, however, the same rules for determining the quantity of air for dilution of the carbonic acid or vapor of water generated, are applied to gas burning as were used in the case of respiration, we have the following results. A $4\frac{1}{2}$ -foot burner will generate 0.0455 cubic foot of carbonic acid each minute, whence 114 cubic feet of fresh air will be needed in the same time to dilute this carbonic acid so that in the

resulting mixture 0.0008 volume of carbonic acid (twice the normal quantity) will be present. The same burner will produce 0.00475 pound of vapor of water each minute, which calls for 85 cubic feet of air, if the condition of adding 5 per cent. to the humidity at 70° is thought to be the standard for attainment.

In the act of respiration, as discussed in the last number, it was shown that 0.000336 pound of carbon was consumed in the system, as measured by the expirations, each minute. The estimate of this quantity is increased by some emitted carbonic acid by transpiration; adding, as before assumed, one-fifth, then 0.0004 pound of carbon can be accepted as consumed each minute. Whence, recognizing that 14,500 units of heat proceed from the perfect combustion of carbon into carbonic acid, it results that 5.8 units of heat will be produced.

From this quantity of heat is to be deducted the heat requisite to vaporize the exhaled moisture from the lungs and from the skin. The previous assumption of vapor emitted each minute, at 0.0014 pound, multiplied by 1062° (= the latent heat of vapor at 70°), gives 1.49 units of heat as absorbed in the evaporation, leaving 4.31 units of heat to be accounted for. What proportion of this heat is taken up by the labor of work, or in the functional demands of animal or mental life is very uncertain.

Taking the 30 cubic feet of air allotted in the last number for the requisite of ample ventilation of a person each minute, we have 30×0.0741 (the weight of one cubic foot of air, of 70 per cent. humidity, at 70° temperature) = 2.232 pounds of air at 70°; multiplying by 0.238, or the *specific heat* of air, we have 0.531 as the number of heat units demanded to heat the 30 cubic feet of air 1°. If it be assumed that all the heat unaccounted for—the 4.31 units—is expended in heating the 30 cubic feet, then the temperature of the 30 feet will be elevated a little more than 8°. It is not probable, however, that the amount of heat to be dissipated exceeds one-half the total, and possibly one-third is nearer the case. I think that the elevation of temperature of the surrounding air, when 30 cubic feet of air per minute is allotted to each adult in still life, does not exceed 3°, but am ready to admit that the grounds for this belief are too nearly a mere guess to be satisfactorily stated.

It is not unfrequent that in a crowded room, in warm weather, a number of persons will be collected together who will have been provided with not over 10 cubic feet of air per minute. On the supposi-

tion above, the temperature of such a room would be raised from 70° to 79° , presenting some probability of coincidence with facts. But the effect of any such elevation of temperature with the supposed limited supply of air, will be to increase the avidity of the air for moisture and to promote perspiration, which will again afford relief by the evaporation of water, and thus limit the proportion of heat given to the surrounding air to temperatures of endurance. As the temperature of air rises, the amount of heat given out by evaporation will increase until it even exceeds that given out by conduction or radiation, or by both combined.

The heat effects from a gas burner are as follows: taking the gas as having the usual quality of 14 to 15 candle power, the heat proceeding from such gas is very nearly ≈ 622 units for each cubic foot of gas burned. [Gas of 14 to 15 candles is such that when 5 cubic feet are burned in a properly shaped burner, under $\frac{1}{2}$ inch water column pressure, in one hour, the light given out will be equal to that proceeding from 14 or 15 standard spermaceti candles, each of which shall burn at the rate of 120 grains of spermaceti per hour.] This gives the hourly heat production from $4\frac{1}{2}$ cubic feet to equal 2800 units, or 46.7 units to be dispensed each minute. The existence of this quantity of heat in combination with the gases of combustion as they arise from the flame, is one of the best established facts in physics, but its dispersal when these gases are diffused is scarcely reconcilable with the observed heat imparted to a closed room by a gas burner. The quantity of heat which will have disappeared by the diffusion is indeterminate. I am not now willing to admit that over one-third the heat which has been theoretically evolved, will have been imparted to the air of a room.

It has been customary to assume that 10 cubic feet of air per minute for each cubic foot of gas burned per hour should be supplied for *ventilation* of a gas burner. This rule gives 45 cubic feet of air for a $4\frac{1}{2}$ foot burner. From such a burner, under such circumstances, the temperature of the air of the room being 70° , that of the air ascending from open burners will be 99° and that ascending from argand burners will be 128° , *on the supposition that none of the heat is wasted in diffusion*. Supposing only one-third of the heat to be imparted to the gases or air of dilution, the temperature of the ascending currents become $79\frac{1}{2}^{\circ}$ and 89° respectively. The real temperature of the gases

rising from the flame of a gas burner, unmixed with air of dilution, may be stated at 2640° . Unless enclosed in a chimney of some kind, these gases rapidly mix with the air around them, until within two or three feet they fall generally below the boiling point. Still the current which reaches the ceiling of a room is generally much elevated in temperature, and spreads over the surface as a stratum, with little tendency to descend or to mix downwards, except by diffusion. This fact and the comparatively brief time of gas lighting, are great aids in meeting the difficulty from heating and from gases of lighting. Another thing must be borne in mind, that there are no organic impurities to be dispersed from the products of combustion. Discomfort, and in extreme cases even suffocation, may follow the want of ventilation of burners, candles or lamps; but disease, in a strict sense, cannot arise from this cause. It is clear that the test of proportion of carbonic acid present, as a measure of vitiation, does not apply to lighted rooms.

It must be noticed that the rate of supply of air for gas burning *i. e.*, 45 cubic feet per minute for a $4\frac{1}{2}$ foot burner, will eventually bring up the rates of carbonic acid in any room (in course of time, however large the room may be) to 0.0014 volume, supposing the normal fresh air to have 0.0004 volume in it, and supposing that no diffusion of carbonic acid occurs through walls or cracks, where air will not circulate as a current.

The ventilation of candles or lamps could be investigated with equal care to that which has been given to gas lights, but it is sufficient to say here that the average candle gives about one-fifteenth the light proceeding from an average gas burner, and about equals the ordinary hand lamp, with oil as the burning material. Either of these can be taken to have somewhat greater heat effects than gas of the same luminous value, and about 5 cubic feet of air per minute can be taken as the quantity needed for each candle or lamp. The carcel or petroleum argand lamps can be estimated at slightly less heat effect for given light production, and the smaller ones will equal two-thirds an average gas burner in this regard; such lamps will require 30 cubic feet of air per minute.

THE JOURNAL

OF THE

FRANKLIN INSTITUTE

Devoted to Science and the Mechanic Arts.

The JOURNAL OF THE FRANKLIN INSTITUTE is issued in monthly numbers, of eighty pages each, largely illustrated, forming two volumes annually.

Its object is to encourage original research, and disseminate useful knowledge in all matters relating to the practical application of science, but more especially to engineering and the mechanic arts.

The number for June, 1881, completed the one hundred and eleventh volume of the JOURNAL, which is now in the fifty-seventh year of its existence, and the present volume has commenced under very favorable auspices.

Under the direction of the Committee on Publication, with its list of able scientists and engineers, as contributors, largely increased, and with the fact that it is the only Technological Journal published in the United States without any private pecuniary interest, sufficient assurance is given that it will maintain its high position as a leading organ of technology and a standard work of reference.

Besides a great variety of matter of general interest, the JOURNAL contains translations from foreign journals, the proceedings of the meetings, and has contributed in a very large degree to the usefulness of the Institute, which should especially commend it to the support of the members.

The Committee on Publication are desirous of increasing its circulation, being fully assured that it will more than repay the small outlay required to secure it.

As the JOURNAL circulates extensively among scientific men, engineers and manufacturers, advertisers will find it to their advantage to avail themselves of its advertising columns.

SUBSCRIPTION PRICES.

To Members,	\$3.00 per Year.	Single Copies, 25 cents.
To Non-Members,	5.00 per Year.	Single Copies, 50 cents.

RATES OF ADVERTISING.

	1 YEAR.	6 MONTHS.	3 MONTHS.	1 MONTH.
1 PAGE,	\$60	\$32	\$18	\$10
$\frac{1}{2}$ " "	32	18	14	6
$\frac{1}{4}$ " "	18	14	10	4

Communications for the JOURNAL and business letters should be addressed to the Secretary of the Franklin Institute, 15 South Seventh street, Philadelphia, Pa.